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THE STRENGTH OF BITUMINOUS MIXTURES AND THEIR BEHAVIOR UNDER REPEATED LOADS

MARCH-1956
No. 15

by
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THE STRENGTH OF BITUMINOUS MIXTURES AND THEIR

BEHAVIOR UNDER REPEATED LOADS

TO: K. B. Woods, Director
Joint Highway Research Project

March 13, 1956

File: 2-5-5-10
C-36-6J

FROM: Harold L. Michael, Assistant Director

The attached paper entitled "The Strength of Bituminous Mixtures and Their Behavior Under Repeated Loads" by L. E. Wood and W. H. Goetz, presented to the annual meeting of the Highway Research Board in January, 1956, was prepared from data being obtained in the bituminous laboratory on the general problem of mixture stability.

While the data do not apply to Indiana AH Type B mixtures specifically, they were collected as a basic part of the study of this stability problem. The relationships developed are fundamental to an understanding of bituminous mixture behavior particularly when used as a portland cement concrete overlay. It would seem that the relationships established have application to a wide variety of mixtures.

Data of the type included in the paper for sheet asphalt mixtures currently is being obtained on bituminous concrete mixtures conforming to Indiana AH Type B specifications.

Respectfully submitted,

Harold L Michael

Harold L. Michael, Assistant Director
Joint Highway Research Project

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Attachment

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THE STRENGTH OF BITUMINOUS MIXTURES AND THEIR BEHAVIOR UNDER REPEATED LOADS

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For Presentation at the 35th Annual

Meeting of the Highway Research Board

Washington, D. C.

January 17-20, 1956

INTRODUCTION

From the very beginning of bituminous paving construction there has been a lack of knowledge regarding the actual interrelationships existing among stability, temperature, and rate of loadings for bituminous mixtures. This lack of knowledge has led to the development of a number of so-called "empirical" tests used in the design of these mixtures. The results of these tests, when correlated with certain field conditions, gave rise to design criteria in current use.

These empirical tests have been adequate for the most part, since their development came during a period of little change in traffic intensity and tire pressures. Field correlations, once established, could be used again and again. However, in recent years, with the advent of greater traffic intensities and higher tire pressures, the empirical tests have failed to answer adequately the question of what should constitute proper design criteria for conditions other than those that were used to establish the original design criteria.

From the wide variation of test procedures used in current design methods it is evident that there is a definite lack of understanding regarding the fundamental behavior of bituminous mixes. Most of the present day design criteria leave much to be desired as to how the mixture would react under conditions of loading and temperature other than those for which the correlation was established. In some cases, they are based upon test values obtained from rates of deformation and temperatures such that the mixes being tested exhibit definite elastic properties. However, present day thinking has begun to recognize the importance of plastic action in bituminous mixtures as evidenced by the current papers of Neppe

(1), Mack (2), and Nijboer (3)

It is known that bituminous materials show properties which differ widely from those of elastic materials. The deformation which bituminous materials undergo is thought to be made up of two distinct parts: 1. plastic and 2. elastic. These two components may vary widely under different conditions of loading and temperature.

Field performance indicates that extreme conditions of loading for a bituminous layer occur during summer climatic conditions under a stationary load or at locations where heavy trucks with high tire pressures undergo slowing or stopping movements. The plastic component of deformation under these conditions assumes major importance. The proper mixture design should minimize this component.

While it is important that a mixture should have sufficient stability under the above conditions, it must be remembered that winter temperatures impose a situation upon the mixture such that it acts more like an elastic body. Under low temperatures, the mixture could become quite brittle.

An adequate design procedure should answer the question as to how the mixture would react under wide ranges of temperature, rates of loading, and types of loading. Based upon current design concepts, a mixture may qualify for use in a road. Under actual field conditions, it may have undesirable characteristics which should be detected before the mixture is placed.

For many years, the Indiana AH type (B) mix has given satisfactory service. Recently, in some areas, bituminous concrete overlays made from this mix are showing signs of distress such as rutting and shoving in the wheel-tracks. It is theorized that two factors have brought about this situation: 1. Heavier wheel loads have increased the stress that the

overlays experience, and 2. Increased repetitions of load have increased the accumulated permanent deformation. The combination of these two factors has brought about a situation such that plastic deformation becomes a significant factor. This plastic deformation is not recoverable; the lanes experiencing the majority of the wheel loads are permanently deformed. This action is especially noted in the vicinity of stop lights where the stresses in the overlay are applied slowly and over a longer period of time than on the open stretch of road.

To be able to devise a more rational test for determining performance characteristics of a proposed bituminous mix, it is necessary to have a relationship established between strain rate, temperature, intensity of load, and the number of load repetitions. It was for this purpose that this investigation had its inception.

OUTLINE OF INVESTIGATION

A fundamental part of this investigation was the selection of a test method for evaluating strength and deformation characteristics of a bituminous-aggregate mixture while undergoing repeated loads. It was first necessary that a relationship should be established among the following variables: temperature, rate of deformation, and stability. For the case of repeated loads a fourth variable was added, the number of loading cycles necessary to reach some failure criterion.

Purpose and Scope

To establish a relationship among rate of deformation, temperature, and stability, a series of specimens must be tested at varying rates of

deformation and temperatures. Stability values at these levels must be ascertained. By using regression analysis, a mathematical model can be determined that best expresses the desired relationship. The relative importance of a unit change in temperature or a unit change in the rate of deformation upon the stability can then be determined by differentiating the expression first with respect to temperature and then with respect to rate of deformation.

In the present day design methods there is a wide variation in the rate of deformation and temperature used in the various test procedures It is felt that a general relationship of stability, rate of deformation, and temperature could be applied to a wide range of test methods. To establish the relationship, only the parameters would have to be evaluated and this could be done with a limited number of tests. This relationship, once established, would yield information as to the manner in which the mix would react under varying conditions of rate of deformation and temperature.

For studying the effect of repeated loads, it was felt that there would be some combination of applied stress and number of load repetitions at any one test level that would lead to a failure as defined by some suitable criterion. This failure criterion would be defined as the point where excessive shear deformations are observed. By obtaining deformations at each loading cycle and plotting these data, one should be able to locate the point of excessive shear deformation and determine the number of loading cycles necessary to cause this condition.

From this information, relating temperature, rate of deformation, applied stress, and number of load repetitions could be derived.

Testing Methods

Many test methods have been proposed by which various properties of bituminous paving mixtures can be evaluated: triaxial test (4), Hubbard-Field test (5), Hveem Stabilometer test (6), and the Marshall test (7). For the purpose of this study it was felt that a relatively simple test which enables one to obtain stress-deformation data at varying rates of deformation and temperatures was desired. This led to the choice of the unconfined compression test using a rational-sized specimen. The unconfined compression test was one of the earliest tests proposed for evaluating mixture properties (8, 9). More recently, the triaxial test has received rather wide acceptance since it enables one to determine two important mix characteristics: the angle of internal friction and the cohesion. The unconfined compression test may be thought of as a special case of the triaxial test where the confining pressure is zero. Figure 1 shows a typical stress-deformation plot and notes the items of interest for this study.

An unconfined compression type test would also lend itself to the study of repeated loads and their effect upon mixture properties. This would enable one to maintain a continuity of concept through the two phases of the study.

RELATIONSHIP OF STRESS AND DEFORMATION

FOR AN UNCONFINED COMPRESSION TEST

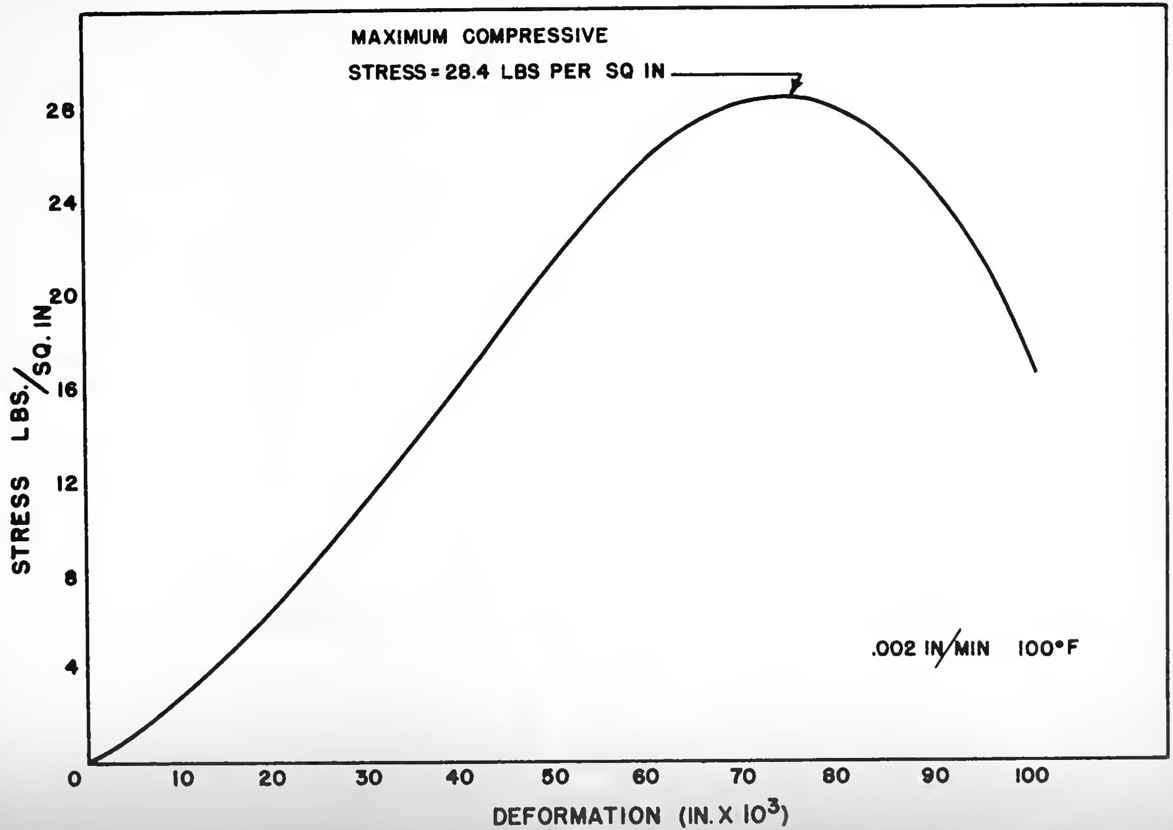


FIGURE I

EXPERIMENTAL WORK

The emphasis in this study was the development of a relationship which included, first, the rate of deformation, temperature, and maximum compressive stress, and later included the number of load repetitions Therefore, the composition and method of compaction of the mixture was held constant. The materials used for this mixture and the method of forming and testing the specimens are described in this section.

The mixture chosen for this study was a sand asphalt. This mixture permitted the use of relatively easy molding procedures and made it possible to utilize the testing equipment available in the laboratory immediately.

Materials

The sand used in this study was a local, natural material obtained from a river terrace. The gradation chosen met the requirements of ASTM D978-54 Standard Specifications for Asphaltic Mixtures for Sheet Asphalt Pavements, Surface Course, Grading No. 2 (10) and Asphalt Institute 100-XI Sheet Asphalt Surface Course (11). The sieve analysis of the gradation is presented in Table I and depicted graphically in Figure 2. The control of the gradation was obtained by drying the sand, sieving it into the respective sizes as shown in Table I and recombining it by weight in the desired proportions.

As the terrace sand was deficient in the minus 200 material, this fraction was obtained by adding pulverized limestone. By altering the character of the minus 200 material, two mixtures were formulated. These two mixtures are designated as I and II. Mixture I was obtained by using

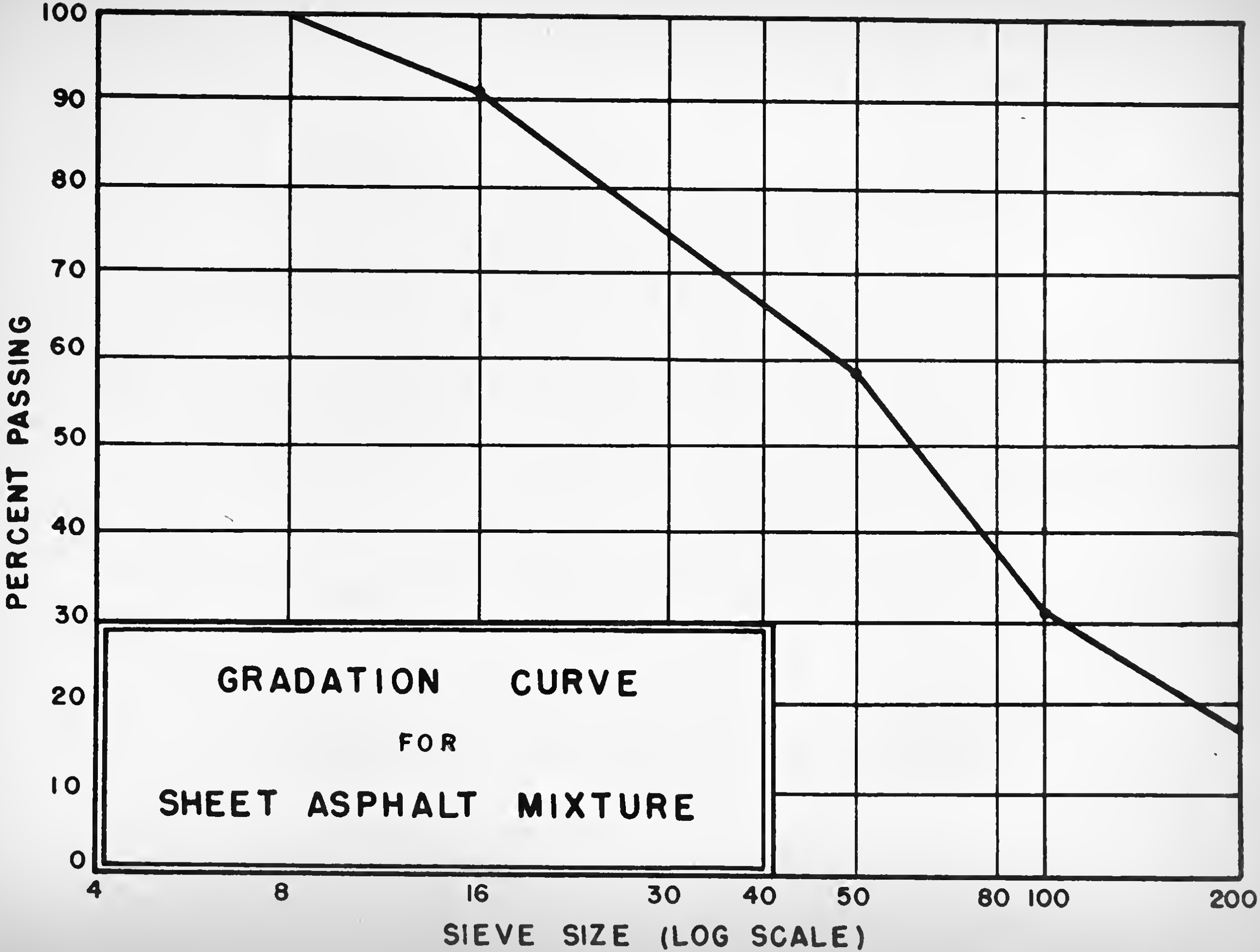

GRADATION CURVE
FOR
SHEET ASPHALT MIXTURE
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
4
8
16
30
40
50
80
100
200
SIEVE SIZE (LOG SCALE)

FIGURE 2

TABLE I

Sieve Analysis

Sieve		Percent by Weight
Passing	Retained	
#4	#8	0
#8	#16	7
#16	#50	34
#50	#100	27
#100	#200	15
#200		17

a commercial limestone mineral filler. Mixture II was obtained by using an agricultural limestone from which was removed the material retained on the 200 sieve.

Penetration, 77°F, 100g. 5 sec.	66
Specific Gravity @ 77°F/77°F	1.015
Ductility @ 77°F, 5 cm./sec.	150+ cm.

Procedure

The mixtures used in this study were those in which the aggregate and asphalt were heated separately and then combined in a hand mixing operation. The individual sand fractions were combined to give the correct gradation (see Figure 2). The aggregate was heated in an electric oven to a temperature of about 325°F. The asphalt was heated in a gas oven to a temperature of 300°F.

The constituents were mixed by hand for a period of two minutes in a heated porcelain bowl using a metal spoon, and then molded into a specimen two inches in diameter and four inches in height by a double-plunger compaction method which included rodding the material into the mold. To control the densities of the specimens, care was taken to introduce the same amount of material into the mold each time. An Ames dial device was used to insure that each specimen was compacted to four inches in height (see Figure 3)

The molding procedure consisted of placing the hot bituminous-aggregate mixture into a hot steel mold in three equal lifts. Each lift was tamped thirty times with a heated rod. A hydraulic-compaction device was used to compact the specimen. The specimen height was the determining factor for establishing the static axial load which was applied to each end of the specimen. The specimen was left in the compaction device under

load for two minutes after which the load was released and the mold was removed immediately from the specimen. The specimens were allowed to cure for two days in laboratory air which had a temperature of 75 $\pm$ 5°F. The specimen's height, diameter, and weight were obtained at this time for bulk density calculations. The specimens were then stored in a freezer at a temperature of 20°F until used in tests.

The asphalt content used in this mixture was 9% based on the weight of the aggregate. This value was determined from the Hubbard-Field design procedure.

Mixture I was used to establish the relationship among maximum compressive stress, rate of deformation, and temperature of test. Specimens were tested to failure in the unconfined state at five rates of deformation: 8.65, 2.0, 0.2, 0.02, and 0.002 in./min. At each of these rates, three temperature levels were used: 40°, 100°, and 140°F. These temperatures were maintained during the test by means of a water bath. Specimens were placed in the bath for one half hour before the start of the test. Duplicate specimens were run at each test condition.

It was hypothesized that the relationship, previously established, would hold true for different mixtures; only the numerical constants would need evaluating and a limited number of tests would be necessary for the evaluation. Mixture II was used to check the above assumption. Unconfined compression tests were run at the following levels: 40°F - 0.02 in./min., 100°F - 0.2, 0.02, and 0.002 in./min., and 140°F - 0.02 in./min. To verify the predicted values, unconfined compression tests were run at the preceding conditions. In all cases but one there was very close agreement between the predicted values and the observed values.

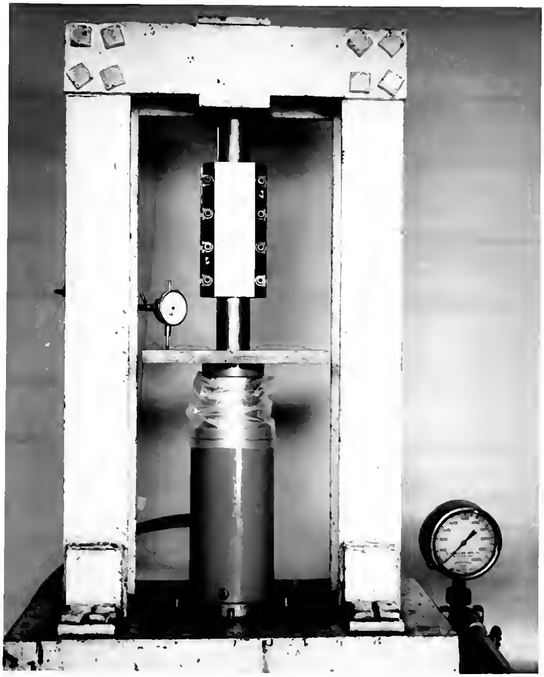


Figure 3.

The repeated load sequence was performed by utilizing a combination mechanical and hydraulic system (see Figure 4). The rate of deformation was controlled by the mechanical testing machine. A hydraulic jack was used in the system to obtain the immediate release of load when the desired load on the specimen was reached. The deformation was measured directly from the top of the specimen.

In the repeated load sequence, three rates of deformation were used: 0.2, 0.02, and 0.002 in/min. At each of these testing speeds, three temperatures were used: 40°, 100°, and 140°F. For each test condition the load was cycled at 75%, 50%, and 25% of the maximum compressive stress for that particular test condition. Figure 5 gives a general representation of three cycles of load repetitions. Deformation measurements were taken so that the elastic rebound and permanent deformation could be determined. The dotted portion of the curve indicates that the period of time between loadings was an undetermined variable. A sufficient period of time was allowed between load applications in order to permit most of the retarded rebound to take place.

Figure 4.

GENERAL RELATIONSHIP BETWEEN DEFORMATION AND TIME FOR REPEATED LOAD CYCLES

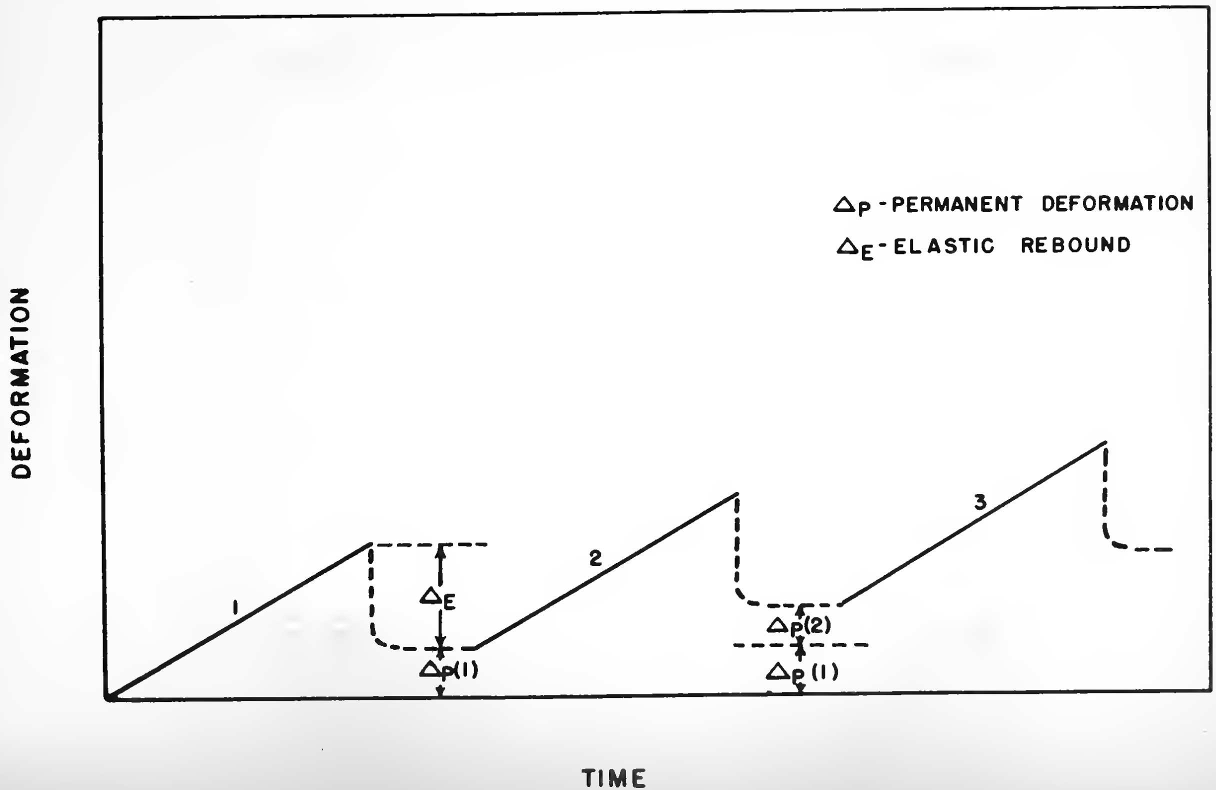


FIGURE 5

RESULTS

In the first phase of this study, strength-deformation data were obtained at various temperatures and rates of deformation. In the second phase, deformation data for load repetitions at various stresses, temperatures, and rates of deformation were obtained.

Effect of Temperature and Rate of Loading

Hot-mix, sheet asphalt specimens were tested to failure in unconfined compression at varying temperatures and rates of deformation. The results of this study are shown in Table II. The resulting maximum compressive stress values were plotted against rate of deformation at the different temperature levels and curves were drawn through the resulting points. The maximum compressive stress values were also plotted against temperature at the different rates of deformation. Again, curves were drawn through the resulting points. These graphs are shown in Figures 6 and 7. It can be seen that a change in temperature for any one rate of deformation has a more pronounced effect on the maximum compressive stress than does a large change in the rate of deformation for any one temperature.

It was desired to express these results in a mathematical equation. A general mathematical model for the family of curves shown in Figure 6 is as follows:

$$X_o = A^{BX_1^{(CX_2 + D)}}$$

or: $$\log \log X_o = A' + B' \log X_1 + C'X_2 + D'X_2 \log X_1$$

RELATIONSHIP BETWEEN RATE OF LOADING AND MAXIMUM COMPRESSIVE STRESS AT VARIOUS TEMPERATURES

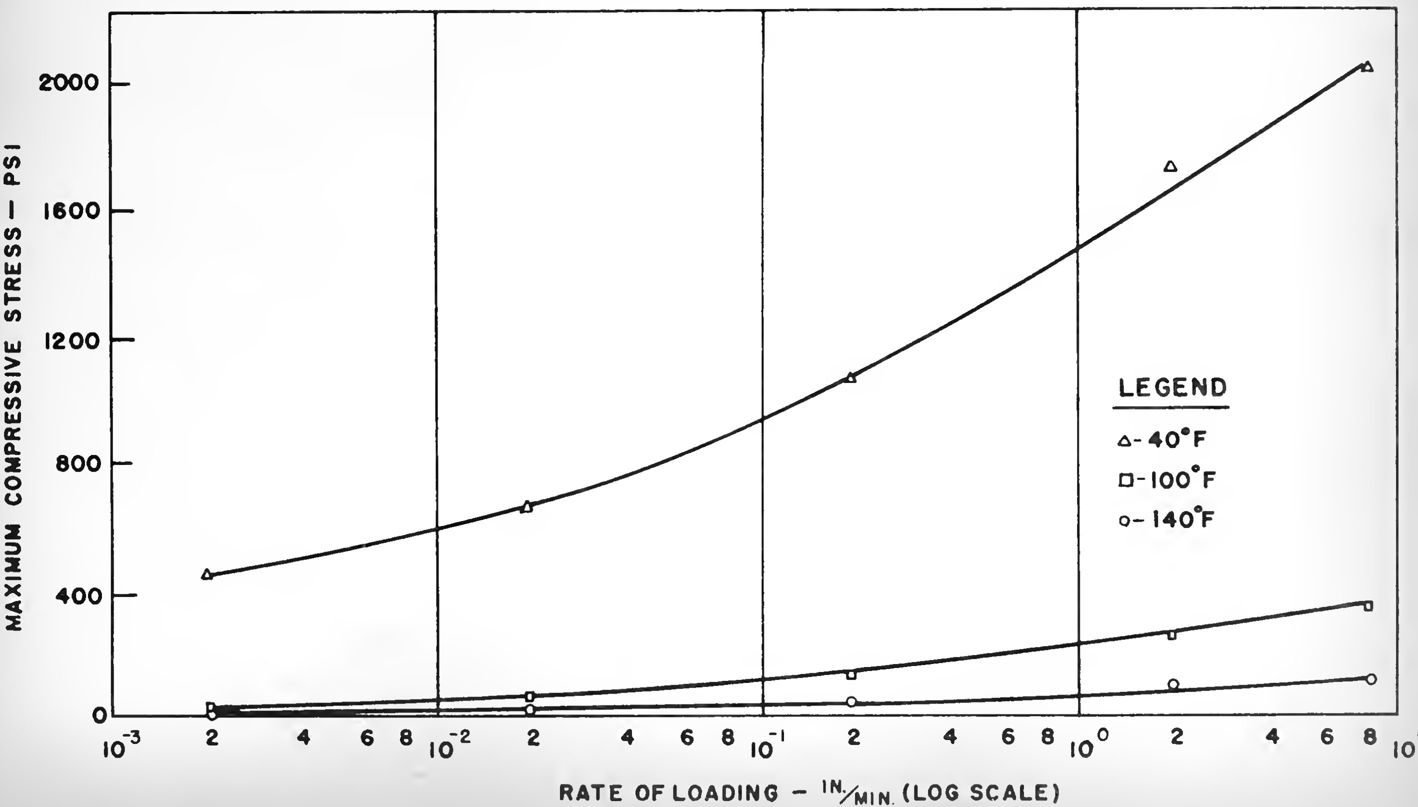


FIGURE 6

RELATIONSHIP BETWEEN MAXIMUM COMPRESSIVE STRESS AND TEMPERATURE AT VARIOUS RATES OF DEFORMATION

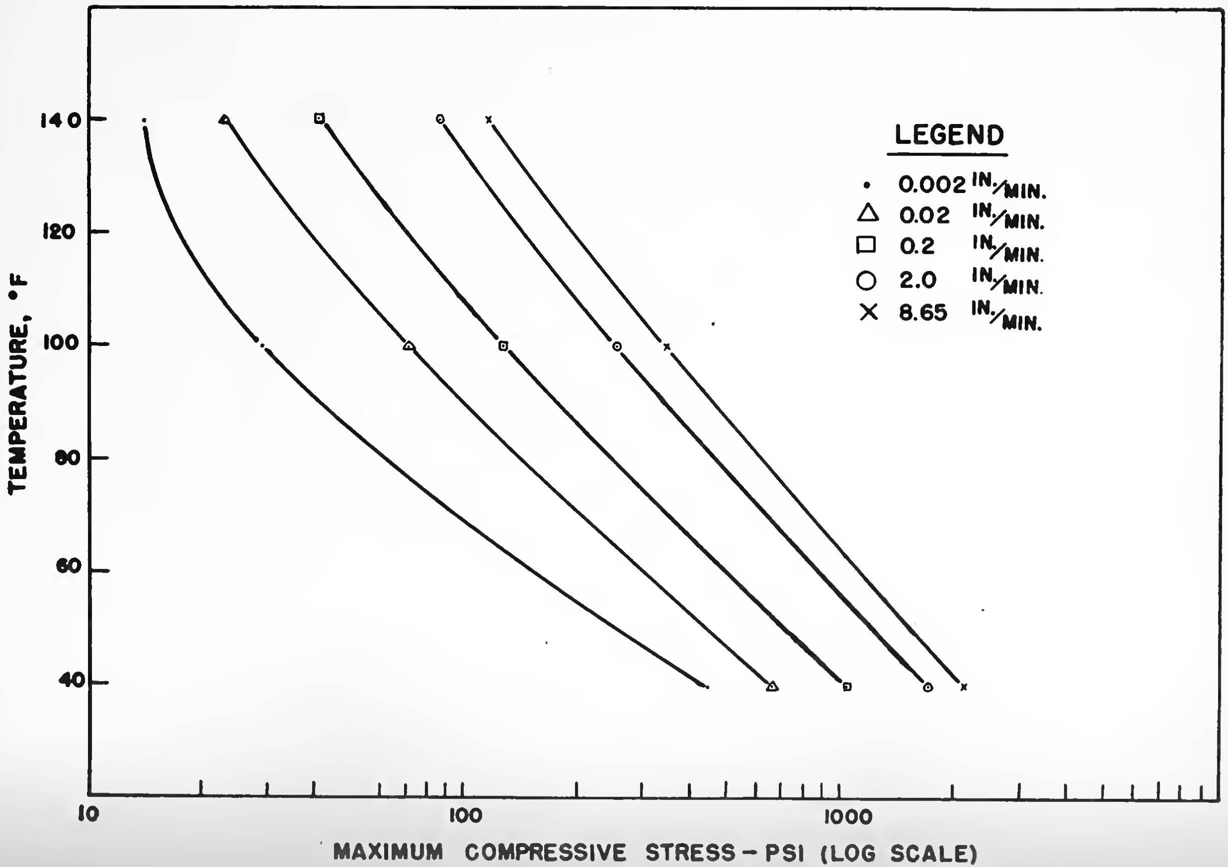


FIGURE 7

where: X_o = maximum compressive stress, psi.

X_1 = rate of deformation, in./min.

X_2 = temperature, °F.

A, B, C, D, A', B', C', D' = constants

The numerical values of the constants for the model were determined by using a least squares approach (12). The complete estimation equation is as follows:

$$\log \log 10X_o = 0.667415 + 0.0105 \log 1000X_1 - 0.00288X_2 + 0.000294X_2 \log 1000X_1$$

With this equation one should be able to make a good estimation of the unconfined compressive stress for many temperatures and rates of deformation for mixture I.

The extent of association of the above expression was evaluated by use of multiple linear regression analysis (13). This was done to determine how well the estimated values of X_o represent the observed values of X_o for the different test conditions. The extent of association is measured by the multiple correlation coefficient which in this case was 0.99.

With this close correlation, then, by using the above model, it should be possible to define the relationship between maximum compressive stress, rate of deformation, and temperature for any chosen mix with a limited number of tests by merely performing enough tests to determine the various constants.

As was mentioned in the procedure, the character of the mix was changed by altering the minus 200 material. The results of this series are shown in Table III and graphically depicted in Figure 8. Maximum compressive strength is plotted against rate of deformation at various

TABLE III

Unconfined Compression Test Data for Mixture II

Temperature	Rate of Deformation - in./min.		
°F	0.002	0.02	0.2
	Maximum Compressive Stress in psi.		
40	420*	649[1] 464[2]	1035*
100	29[1] 21[2]	50[1] 46[2]	91[1] 100[2]
140	8*	14[1] 16[2]	26*

* Values and data used in re-establishing mathematical relationship for new mixture.

[1] Calculated values.

[2] Observed test values taken after the relationship for Mixture II was established.

RELATIONSHIP BETWEEN RATE OF DEFORMATION AND MAXIMUM COMPRESSIVE STRESS AT VARIOUS TEMPERATURES

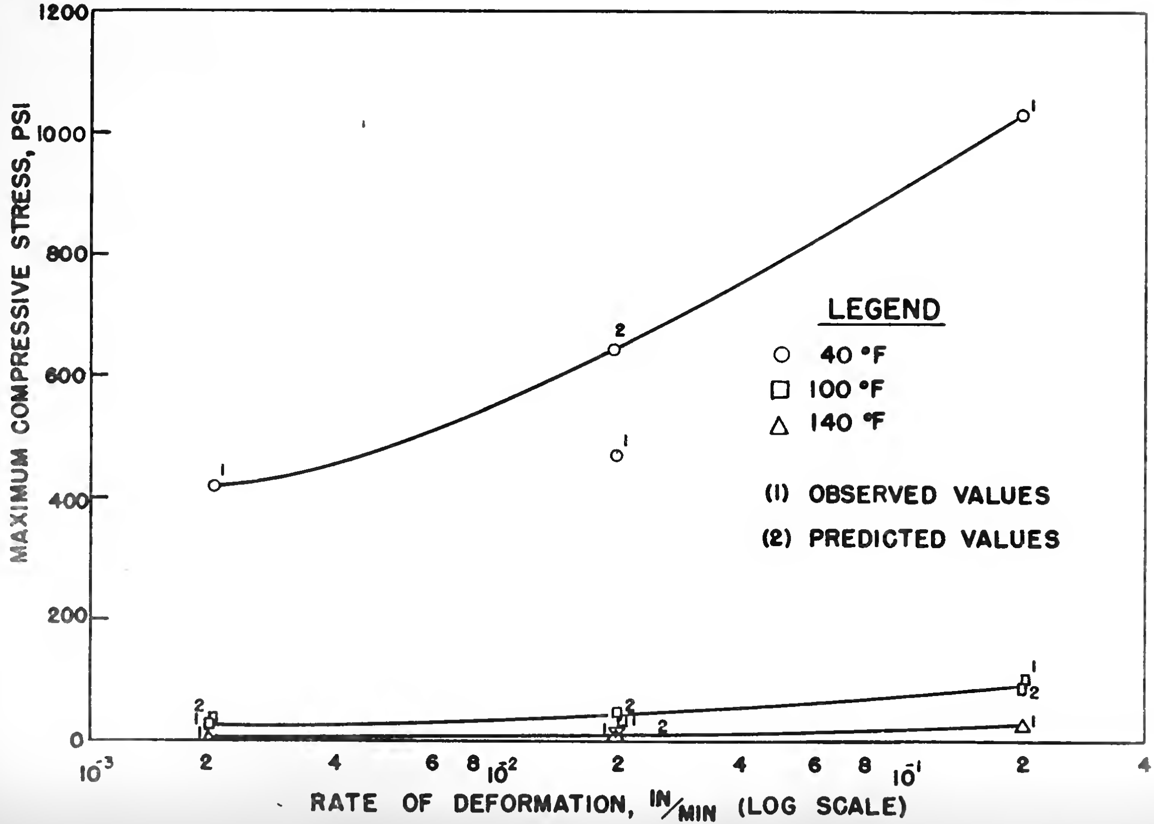


FIGURE 8

temperatures. A comparison can be made between the calculated values and the observed values.

Effect of Load Repetition

In the second part of this study, an evaluation of the effect of repeated loads upon an unconfined specimen was undertaken. These repeated loads were applied at varying rates of deformation and temperature and at fixed percentages of the maximum compressive stress for any one test level. The total deformation and amount of permanent deformation for each load cycle was measured. A sufficient period of time was allowed between load applications in order to permit most of the retarded rebound to take place. In general, at the lower temperature, a longer period of time was necessary to recover the retarded rebound than at higher temperatures. The results of this study are shown in Table IV.

The effect of repeated loads at varying percentages of maximum compressive strengths as determined for 0.2 in./min. and 40°F is shown in Figure 9. The top line represents an applied stress of 777 psi, which is 75% of the maximum compressive stress. The middle line represents an applied stress of 518 psi, which is 50% of the maximum compressive stress. The bottom line represents an applied stress of 259 psi, which is 25% of the maximum compressive stress.

The relationship starts out as a straight line on a semi-logarithmic plot in all cases. At some stage, dependent upon the applied stress, the plot deviates sharply from the straight line, as is shown in the upper two curves. What occurs at this point of deviation is a matter of conjecture. It is hypothesized that the asphalt film between particles is being reduced

TABLE IV
Results of Repeated Load Study
Number of Load Repetitions Necessary to Cause Failure*

Temperature °F	% Max. Comp. Stress	Rate of Deformation - in./min.		
		0.002	0.02	0.2
40	75	3	4	5
	50	7	7	7
	25	**	**	28 ≠
100	75	4[3]	3	4[3]
	50	**[2]	4	7
	25		**	**
140	75	3	2[3]	5[3]
	50	6	5	7
	25	**	**	35 ≠

* For definition of failure, see text.

** Number of load repetitions used during test did not cause failure.

1 Run at 67% of maximum compressive stress

2 Run at 33% " " " "

3 Run at 60% " " " "

RELATIONSHIP BETWEEN PERMANENT DEFORMATION AND NUMBER OF LOAD REPETITIONS FOR VARIOUS APPLIED STRESSES

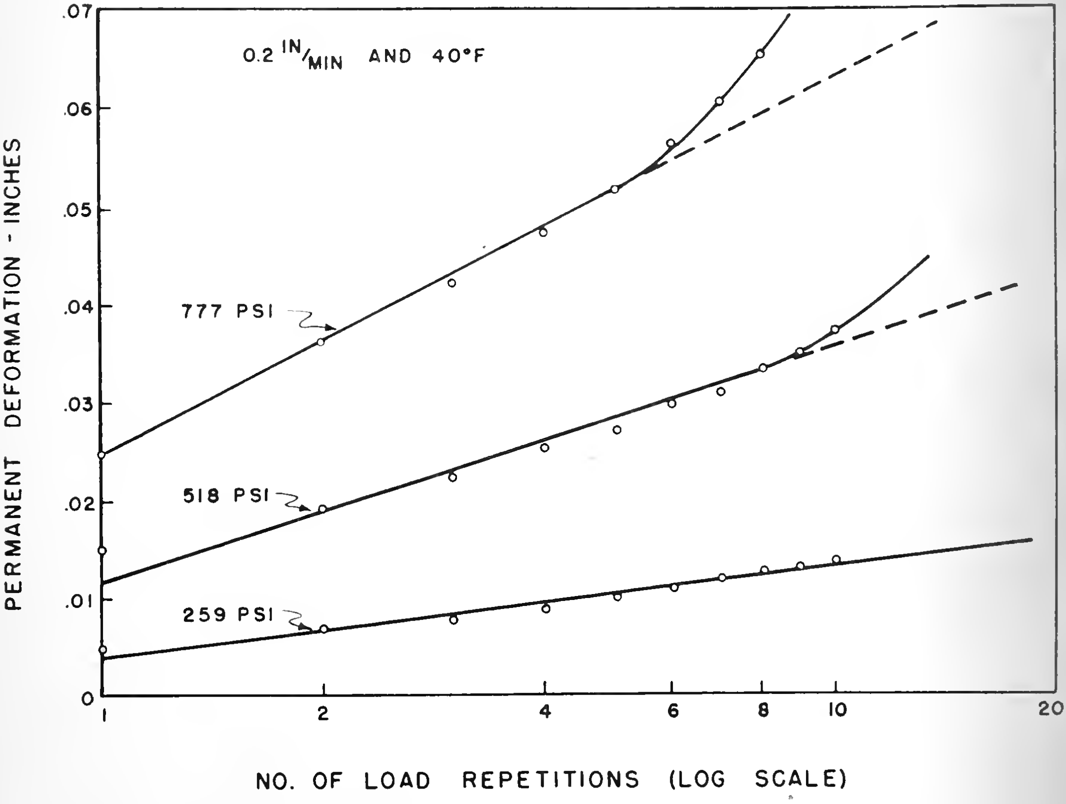
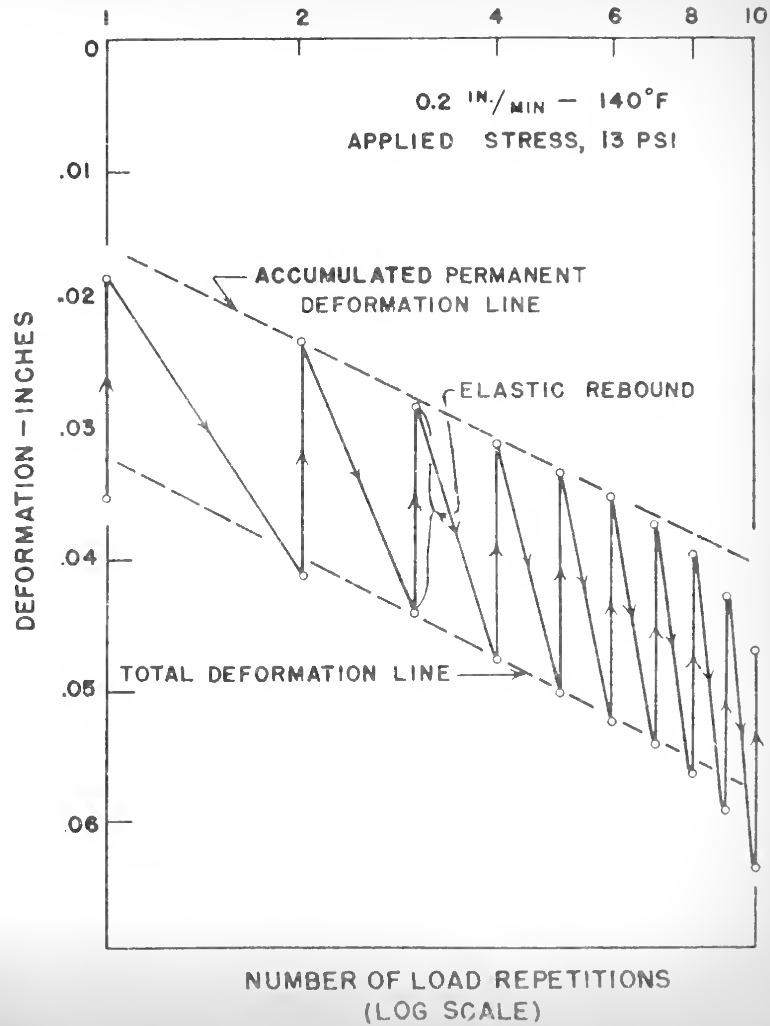


FIGURE 9

in dimension until some critical thickness is reached. At this point, in order to sustain the load, the adjustment in the specimen takes place by reorientation of the aggregate particles themselves. This gives rise to excessive shear deformations which show up as permanent deformations. The point where excessive shear deformations occur was taken as the failure criterion. The elastic part of the deformation takes place principally in the asphalt film which is bound firmly to the aggregate in a polymolecular layer. As the applied stress decreases the number of loading cycles necessary to cause this deviation from a straight line increases. When the applied stress is 25% of the maximum compressive stress, no deviation is observed for the number of load repetitions used in the test, as shown by the bottom line of Figure 9.

A graphical representation of the deformations experienced by a specimen subjected to repeated loads at a temperature of 140°F and at a rate of deformation of 0.2 in./min. is shown in Figure 10. The applied stress in this test is 13 psi. The arrows indicate the deformation record of the specimen while being loaded and unloaded. An important point brought out by this plot is that the elastic rebound appears to be independent of the past deformations the specimen has undergone. The dotted parallel lines show this. These two lines are the accumulated permanent deformation line and the accumulated total deformation line. Even after excessive shear deformations have taken place, the statement appears to be true. This might tend to bear out the concept that the elastic part of the deformation takes place principally in the asphalt films surrounding the aggregate particles.

The curves shown in Figure 11 represent the break-down of the defor-

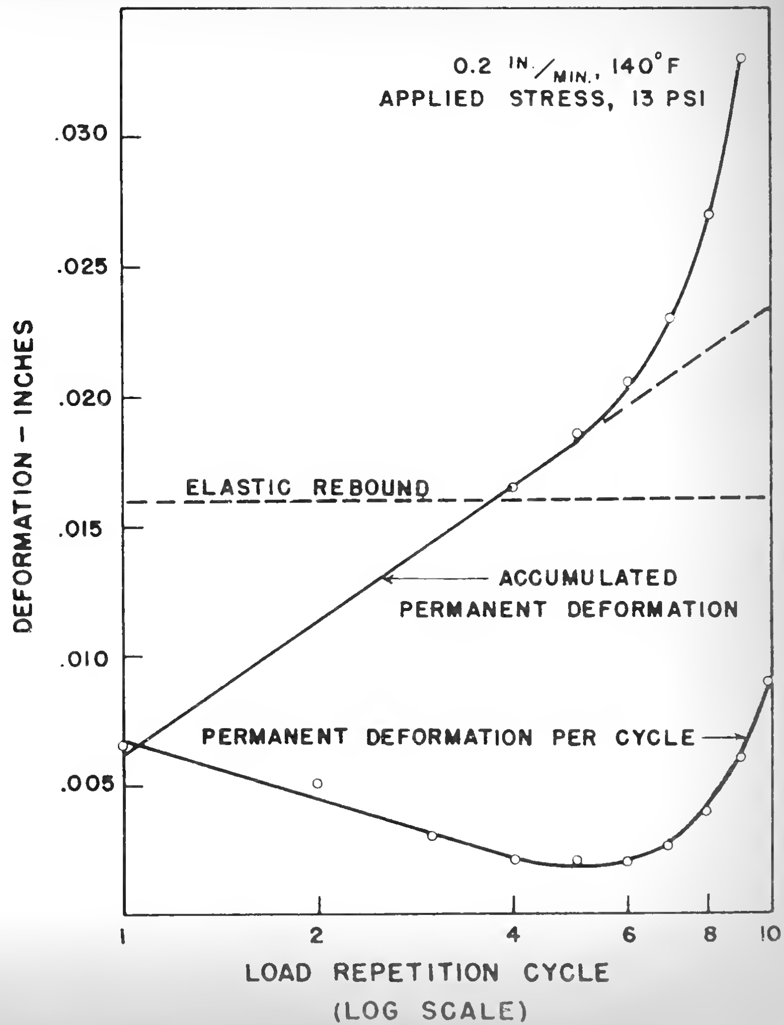


DEFORMATION RECORD

OF A SPECIMEN SUBJECTED

TO REPEATED LOAD

FIGURE 10



RELATIONSHIP BETWEEN
ELASTIC AND PERMANENT
DEFORMATION
WITH REPETITIVE LOADING

FIGURE 11

mation experienced by the specimen for each load cycle in the rejected load test at 0.2 in./min. and 140°F using an applied stress of 13 psi. It shows the elastic rebound as a constant for the duration of the test. The amount of permanent deformation experienced by the specimen for each load cycle decreases to a minimum point and then increases rather sharply. It can be seen upon examination of the accumulated permanent deformation curve that this sharp increase in permanent deformation per cycle results in the deviation from a straight line plot. This is the point where it was postulated that excessive shear deformations became important.

Figure 12 shows the relationship between the applied stress and the number of load repetitions a specimen was able to stand at 140°F and varying rates of deformation before an excessive shear deformation, which was defined as a failure criterion, was observed. The minimum point of the curve shown in Figure 11 would show on the 0.2 in./min. plot at 13 psi and 7 cycles. Under each test condition there appeared to be an applied load that could be cycled a large number of times without excessive shear deformations occurring. At some levels no further increase in permanent deformation was noted after a small number of load applications. This stress in each case was labeled as the endurance limit. At each test level the endurance limit was approximately 25% of the maximum compressive stress. The endurance limits at 140°F for 0.2, 0.02, and 0.002 in./min. are shown as 7 psi, 4 psi, and 2 psi respectively. The asphalt film must be able to absorb these stresses since no particle reorientation occurred. It can be noted that a large change in the rate of deformation did not bring about too great a change in the endurance limit.

The effect of the temperature, on applied stress-endurance limit

APPLIED STRESS - ENDURANCE LIMIT

RELATIONSHIPS AT VARIOUS RATES OF LOADING

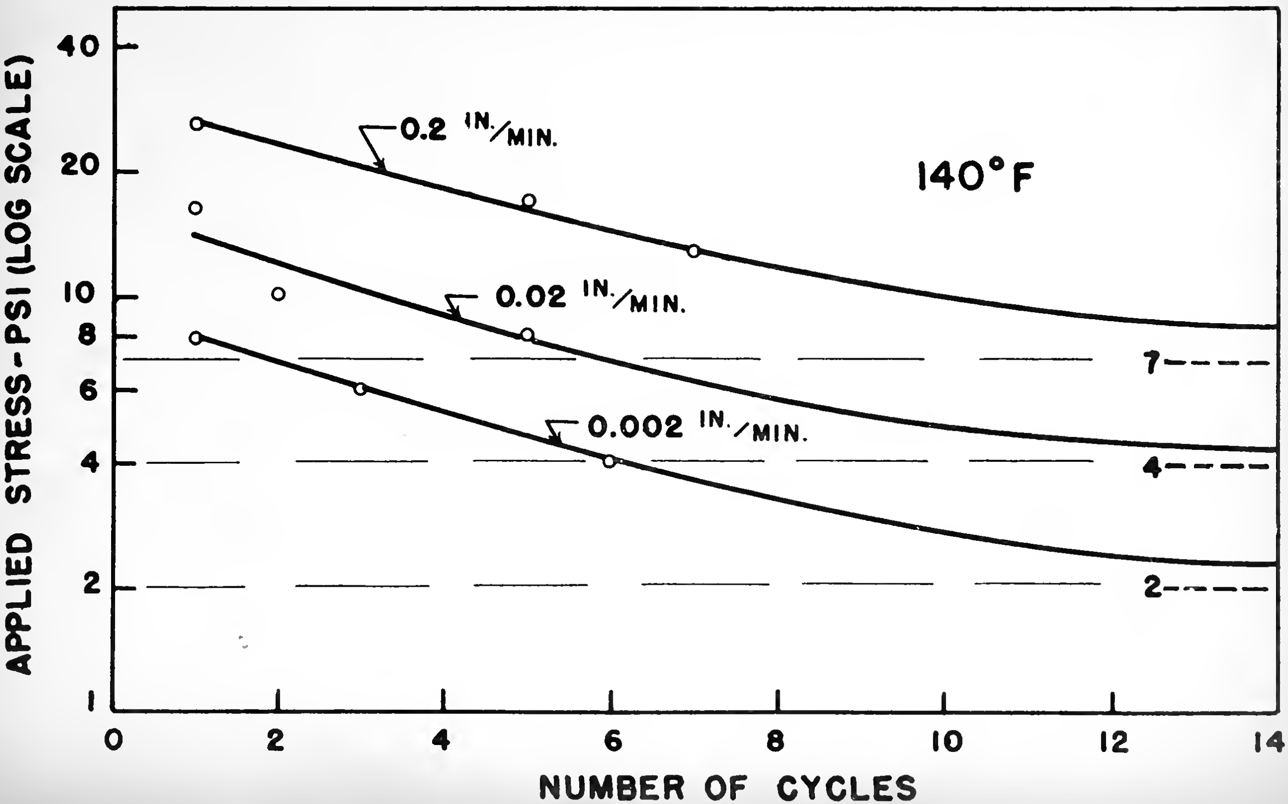


FIGURE 12

relationships at one rate of deformation, 0.2 in./min., is shown in Figure 13. Here it can be seen that a change in temperature results in a large change in the endurance limit. The endurance limits at 0.2 in./min. for 40°, 100°, and 140°F are shown as 259 psi, 25 psi, and 7 psi respectively. Again it can be seen, that a decrease in the applied stress permits a specimen to withstand a greater number of load repetitions before the failure criterion is reached.

Figure 14 enables one to make a comparison of the relative effects of the rate of deformation and temperature upon the endurance limit. It can be seen that the temperature has a much greater effect upon the endurance limit than does the rate of deformation. For example, at a temperature of 40°F, changing the rate of deformation from 0.2 in./min. to 0.002 in./min. lowers the endurance limit from 259 psi to 105 psi. At a rate of deformation of 0.2 in./min. changing the temperature from 40°F to 140°F lowers the endurance limit from 259 psi. to 7 psi.

It was desired to express the curves in Figure 14 in a mathematical model. The model for any one test condition is:

$$X_o = \left[E \cdot 10^{-\varphi (n-1)^{\beta}} + (1-E) \right] X\ max.$$

where: $X\ max.$ = maximum compressive stress for the test condition (fixed rate of deformation and temperature).

X_o = applied, cycled, compressive stress in psi.

n = number of load repetitions necessary to cause excessive shear deformation.

E, φ, β = constants that are dependent upon mixture composition.

From this model it can be seen that when $n = 1$, $X_o = X\ max.$ This is not exactly correct according to the failure criterion developed since

APPLIED STRESS - ENDURANCE LIMIT RELATIONSHIPS AT VARIOUS TEMPERATURES

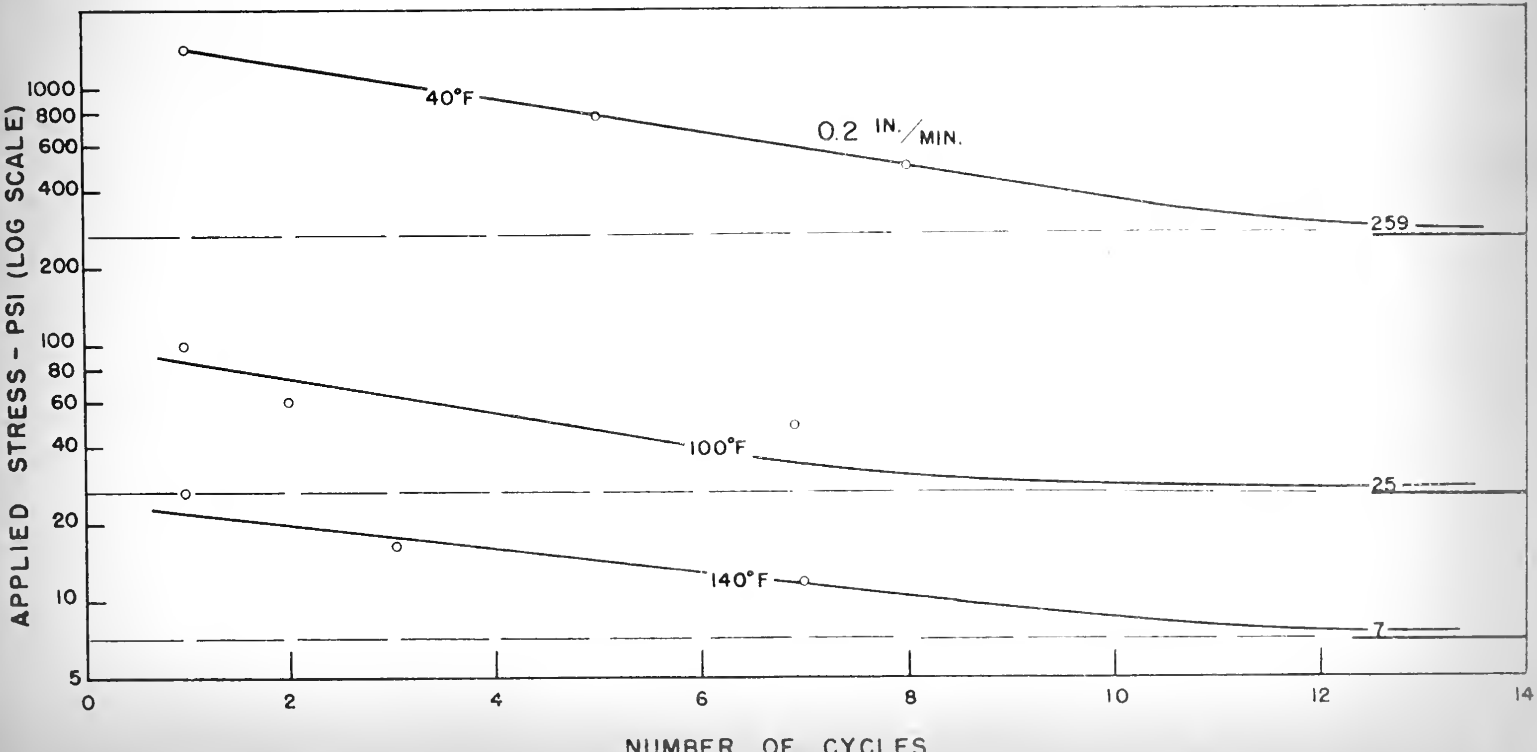


FIGURE 13

APPLIED STRESS—ENDURANCE LIMIT RELATIONSHIPS AT VARIOUS TEMPERATURES AND RATES OF LOADING

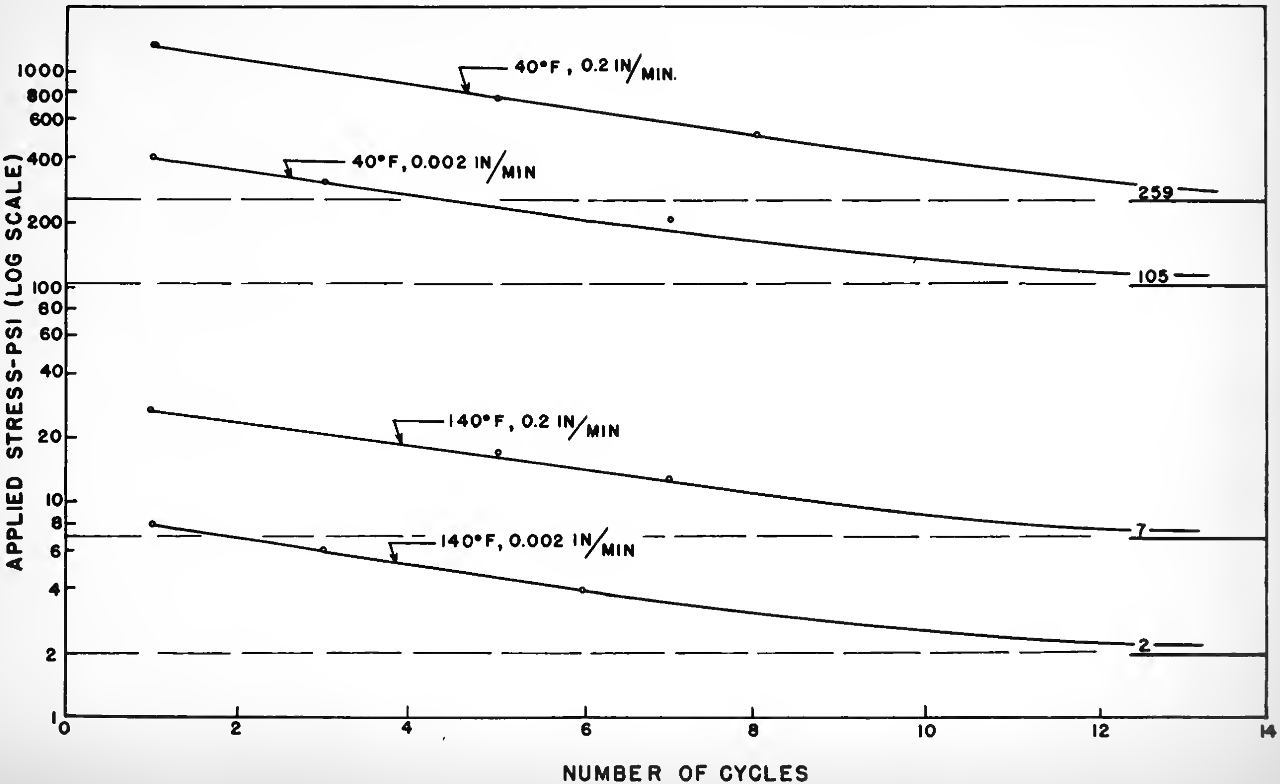


FIGURE 14

this means the specimen would withstand one cycle of the maximum compressive stress. However, in the interests of a general expression, it was felt that this discrepancy was not a major source of error. As n increases we observe the applied stress that can be sustained, decreases. The limiting case of X_o, which was called the endurance limit, develops as n gets large and the term $E \cdot 10^{-\varphi(n-1)^{\beta}}$ approaches 0. In this situation, the endurance limit equals (1-E) X max.

A general expression that would include both phases of the work could be expressed as:

$$X_o = A^{BX_1(CX_2 + D)}\left[E \cdot 10^{-\varphi(n-1)^{\beta}} + (1-E)\right]$$

or:

$$\log \log X_o = A' + B' \log X_1 + C'X_2 + D'X_2 \log X_1 \left[E \cdot 10^{-\varphi(n-1)^{\beta}} + (1-E)\right]$$

where:

X_o = compressive stress, psi

X_1 = rate of deformation, in./min.

X_2 = temperature, ^oF

n = number of load repetitions

$A, B, C, D, E, \varphi, \beta$ = constants that are dependent upon
A', B', C', D' mixture composition.

This model can be used to evaluate the effects of temperature, rate of deformation, and number of load repetitions upon an unconfined, rational specimen. By setting n = 1 it is possible to determine the maximum compressive stress for numerous combinations of test conditions.

The various constants were determined from a least squares approach for the particular mixture composition used in this study. The complete equation is as follows:

$$\log \log 10X_o = 0.667415 + 0.0105 \log 1000X_1 - 0.00288X_2 + 0.000294X_2 \log 1000\,X_1 \left[.75 \cdot 10^{-.1656\,(n-1)^{.537}} + .25\right]$$

SUMMARY OF RESULTS

It must be remembered that this was a laboratory study. The aggregate was of a sheet asphalt gradation and the resulting mixture was more plastic in character than many bituminous concretes. All tests were run in the unconfined state, while in the field it is recognized that mixtures are loaded in such a way that some degree of confinement exists.

With these limitations in mind, the following summary of results is presented:

1. The effect of temperature upon the maximum compressive stress and the endurance limit was more pronounced than was the effect of the rate of deformation.
2. The relationship developed among the maximum compressive stress, rate of deformation, and temperature can be used to obtain information concerning the strength of the mixture under many combinations with tests conducted at a limited number of conditions.
3. The general relationship among stability, rate of deformation, and temperature established by means of unconfined compression tests may hold true for other stability tests used in evaluating bituminous mixes.
4. There was found to be a combination of applied stress and number of load repetitions that resulted in excessive shear deformations. These excessive deformations show up in semi-logarithmic plot of deformation versus number of load repetitions as a deviation from a straight line.
5. It appears that with load repetitions, the asphalt film between

particles is reduced in dimension until some critical thickness is reached. At this point, in order to sustain the load, the adjustment in the specimen takes place by reorientation of the aggregate particles themselves.

6. Limited results indicate that the elastic part of the deformation takes place principally in the asphalt film which is bound firmly to the aggregate in a polymolecular layer.

7. The endurance limit which, in this study was approximately 25 per cent of the maximum compressive stress for all test conditions appears to be an important mix property.

8. The results indicate that the repetitive load test would be a valuable tool in evaluating the adequacy of a bituminous mix

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